CHAPTER 59

USE OF VOLCANOES FOR DETERMINATION OF DIRECTION OF LITTORAL DRIFT

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Abstract - The title of this paper may sound like a joke Correctly the title ought to be "Determination of Direction of Littoral Drift on the South Coast of Iceland by Geomorphological Approach" In order to check the results of such study based on the movements of river entrances and their geometry the use of an accelerometer buoy to be placed in offshore open waters for collection of wave data combined with the results of meteorological data was discussed Then the volcano Surtsey suddenly emerged from 400 ft depth (Nov 1964) and its huge outpours of volcanic material built up an "offshore pole station", where the shoreline development provided some information which supported conclusions from the shoreline study on the mainland Computation of wave energy input provided further information

GEOMORPHOLOGICAL APPROACH

OBSERVATIONS OF RIVER OUTLETS

The littoral drift on the Icelandic south coast was investigated by means of topographic surveys and aerial photos including

Survey by the Danish Geodetic Institute, 1906
Survey by the Danish Navy, ab 1926
Aerial photography, 1945 (Icelandic Survey Dept)
Aerial photography, 1960 (Icelandic Survey Dept)
Aerial photography, 1960 U S Navy
Aerial photography, July 1963 (Icelandic Dept of Lighthouses and Ports)
Aerial photography, Aug 1963 (Icelandic Dept of Lighthouses and Ports)

Most of these surveys were undertaken during the summer period, when the littoral drift because of winds from South East tends to be westward This may have considerable influence on the geographical direction of the outlets of minor rivers on the South Coast while the major streams will not change the general orientation of the outlet which points in the direction of the predominant littoral drift

The results of studies of this material are depicted on Fig 1, indicating that the littoral drift at Holsá is eastward, that the drift at the shore between Affall until west of Holtsos is neutral, that the drift from west of Jokulsá and up to Dyrholaey probably is eastward although some minor outlets demonstrate westward direction which, as mentioned above, most likely is a seasonal phenomenon Furthermore that the littoral drift just east of Dyrholaey is westward

Professor Trausta Einarsson in his article on "Suðurstrond Islands og mundunarsaga hennar" published in Timarit, Verkfrædingafelag Islands (Proceedings of the Icelandic Engineering Association), No 1-2, 1966 in section IV "Raðir foksandshóla og forsoguleg staða strandarinnar" explains the development of shore and shoreline configuration west of Dyrholaey from the outlet of Thorsâ and up to Reynisfjall towards the East He takes a closer look at the shores at Dyrholaey Based on the development of ancient and recent shorelines it is quite clear that the shore between Klifandi (Figs 1 and 3) and Skogâ (Figs 1 and 2) has been a "neutral area", which means that the net drift has been relatively small or the drift has taken place in opposite directions according to season and in almost equal quantities on a year round basis The sediments which washed down to shore by the rivers apparently drifted in part towards the Dyrholaey (Dyrhola-island) building up a tombolo (barrier connecting island and main land) and partly westwards towards Vestmannaeyjar (islands south of Iceland - see Fig 1) which caused the development of another major tombolo inside the wave shadow of these islands (Fig 2). With enough "patience" and material available the Vestmanna Islands would finally become connected to the mainland provided current concentrations between island and mainland would not make this development impossible

This confirms the results of the observations of direction of outlets mentioned above The orientation of the shoreline west of Dyrholaey is almost constant 27 degrees north of west

OBSERVATIONS OF SHORELINE DEVELOPMENT OF VOLCANOE SURTSEY

It is in this respect interesting to note the development of shorelines at the volcanoe Surtsey as studied by Thorarinsson (Surtsey Research Progress Reports Nos II and III 1966 and 1967) and by Norrman (Surtsey Research Progress Report No IV, 1968)

Surtsey is a submarine volcanoe, which erupted on Nov 14th, 1963 (Fig 4) at ab 100 meters depth In 6 days an island 600 m long and almost as wide with top elevation of 60 meters came into existence

Gradually the configuration of the island changed to hoof shape, which immediately after Nov 26th (Fig 5) normally was open towards the southwest Sometimes a barrier blocked the opening, however, but it only lasted,until it was broken down by the surf, or until it was blown away by explosions from the volcanoe After the middle of December the island became nearly circular, later more squared because two sides developed to be almost parallel as explained below

Figs 6 and 7 show the development of shorelines at Surtsey during the period from 1964 to 1967 when coarse lava and pebbles normally were available in a narrow beach around the island for longs migration by wave action During extreme storms the solid lava could become exposed, however, in certain sections of the shore As it may be seen from the figures, the general trend of shoreline development was towards a rectangular shape with rounded cornes against SW The island has two almost parallel sides running SW-NE and an accumulation area on the NE side which developed a lagoon between two beach ridges growing out from SW, typical for an "angular foreland". The orientation of the two parallel sides is given in the figures. It may be seen that the average orientation of the two parallel sides in 1964 was 27 degrees E of N, which is identical with the orientation of the shoreline west of Dyrholaey

WAVE ENERGY APPROACH

An attempt was made to study this situation in a more rational way by evaluating the wave energy input on the south coast of Iceland in order to find the direction of shoreline with "neutral drift" No wave energy data were available however. The procedures were based on the Los Angeles formula

$$Q = \tfrac{1}{2}\, k_1 w\, e \sin 2\alpha_b \qquad (1)$$

where Q = the total amount of sand moved in littoral drift past a given point per year by waves of given period and direction

w = total work accomplished by all waves of a given period and direction in deep water during an average year

e = wave energy coefficient at the breaker line for waves of a given period and direction. It is the ratio between the distance between orthogonals in deep water and at the shore line

α = angle between wave crests at the breaker line and the shore line, or the angle between orthogonals and the normal to the shore line (i e $\alpha = \alpha_b$)

k_1 = factor depending on dimensional units and empirical relations It varies with beach slope, grain size, and other variables

The wave energy coefficient may be written $e = \cos \alpha_o / \cos \alpha_b$ and $\sin 2\alpha_b = 2 \sin \alpha_b \cos \alpha_b$

hence $e \sin 2\alpha_b = 2 \cos \alpha_o \sin \alpha_b$ (2)

The relationship between $\sin \alpha_o$ and $\sin \alpha_b$ for different steepness ratios of the waves is given in Fig 8

Neglecting energy dissipation and reflection the total work may be written

$$w = \frac{\gamma \quad H_{1/3}^2 \quad C_{1/3}}{16} \text{ ft-lbs/sec/ft of crest} \qquad (3)$$

Eqs (1), (2) and (3) combined gives

$$Q = \tfrac{1}{2}\ 6{,}3 \quad 10^8 \quad k \quad H_{1/3}^2 \quad T_{1/3}\ e \sin 2\alpha_b \text{ ft-lbs/year/ft of crest} \qquad (4\ a)$$

$$Q = \quad 6{,}3 \quad 10^8 \quad k \cdot H_{1/3}^2 \quad T_{1/3} \cos \alpha_o \sin \alpha_b \text{ ft-lbs/year/ft of crest} \qquad (4\ b)$$

where $H_{1/3}$ and $T_{1/3}$ are the significant wave height and period

Wind conditions in Iceland are characterized by cyclones moving from SW giving rise to variable wind fields The average duration of a cyclone moving from SW towards Iceland is 1 to 3 days The predominate direction of wind wave propagation is towards NE. Usually the cyclones pass south of Iceland but they may also pass north of Iceland Fig 9 shows the characteristic situation during the winter and sommer seasons Fig 10 demonstrates the characteristic wind direction for the three paths of the cyclones As it may be noted from Fig 10 the cyclones give rise to strong winds from the east when they pass south of Iceland In this situation waves propagate from three directions, SW, S and E Field experiments show that high waves from SW occur although the wind has blown from E for some time

Because of the fact that no wave data were available and the Los Angeles formula refers to an average year, it was necessary for a preliminary evaluation to use the average wind conditions Available wind data are meteorological observations covering a period of 10 years Wind data from three meteorological stations, located in the area between Vestmannaeyjar and Dyrholaey, were statistically evaluated Fig 11 shows frequency diagram The average wind speed ranged from 12 to 22 5 knots Hindcasting was based on the SMB method The problem here, as usual, is to determine the fetch A 22 5 knots wind generates a fully developed sea at a fetch of about 135 NM (nautical miles) and a duration of about 14 hours. The wave energy is a function of H^2 and T, and the SMB diagrams indicate that wind speeds of 12 to 20 knots have no practical influence on the significant wave height, when the fetch increases from 100 NM to 250 NM However, there is an increase of one second in the significant wave period For waves generated by the cyclones moving from SW, it is therefore realistic to select a fetch of 250 NM for W and SW For the other directions a fetch of 135 NM was selected This agrees with results of Danish investigations on wave action for the harbour of Vestmannaeyjar The results of hindcasting as well as the calculation of the deep water energy is shown in Table 1

Each direction represents a sector of 45 degrees The actual shore boundary conditions including true shore orientation west of Dyrholaey are shown in Fig 12. In Fig. 13 the shoreline was turned 5 degrees clockwise in order to observe the possible influence of this on the drift direction computed on the basis of input of longshore wave energy

As shown in Fig 12 the W and SE sectors are bounded respectively 39 and 36 degrees, and only half of the E sector is represented west of Dyrholaey Wind direction from the E tends to concentrate in the area around Dyrholaey, partly due to the Bernoulli effect from the nearby Myrdalsjökull (glacier) east of Dyrholaey West of Dyrholaey the wind blows along the shore and increases the longshore wave energy Moreover the wave energy west of Dyrholaey also increases due to a combination of diffraction and refraction at Dyrholaey In this preliminary evaluation, it is difficult to calculate the wave energy from east representing the average year It is possible however, to estimate roughly the wave energy coefficient "e" in Equation (1)

The maximum input of wave energy is determined approximately by the geometric shadow line which gives $e = 0\ 5^2$ The minimum input of wave energy is determined approximately by the 27 degrees diffraction ray which gives a diffraction coefficient of about 0 10 approximately 1 km west of Dyrholaey or $e = 0\ 1^2$ Due to the refraction, one may expect a wave energy coefficient between $e = 0\ 5^2$ and $e = 0\ 3^2$

Diffracted waves are only of importance in the area immediately west of Dyrholaey They break under an angle of approximately 25 degrees with the shoreline Further westwards refraction of waves towards the shore takes place, developing low swells which are superimposed by wind waves corresponding to actual fetches west of Dyrholaey

The numerical calculations carried out in Tables 1-5 with $e = 0\ 4^2$ and ave $H/L = 0\ 025$ (Table 1) refer to the area immediately west of Dyrholaey It may be noted that the H/L-ratio plays an important role, and that turning the shoreline 5 degrees clockwise from the actual direction (Fig 13) changes the resultant energy balance from eastward predominance to westward predominance thereby causing westward drift This still refers to the area just west of Dyrholaey Further westward the importance of E winds tends to decrease because of the shadow by the Dyrholaey headland This in turn would create more tendency to eastward drift Assuming that this is correct, the shoreline should develop slightly convex (turn clockwise) up towards the Dyrholaey apart from a small area influenced by leeside erosion just west of the Dyrhola-point As it may be seen from Figures 2 and 3 this is actually the way shoreline configuration developed It is therefore evidenced that the orientation of shoreline of ab 27 degrees N of W is close to the direction which causes neutral drift The correct average direction may be a few degrees more as is in fact also indicated by the early development of shorelines at Surtsey

CONCLUSION

Although none of the methods used are exact in the true sense of the word, the similarity of the results are noteworthy The development of shorelines of volcanoes popping up from the bottom of the sea, like Surtsey, may be used to determine the direction of littoral drift on nearby shores As a good luck other methods are available, however

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Table 1 Hindcasting

Direction	Wind	Fetch	$H_{1/3}$	$T_{1/3}$	$H_{1/3}/L_{1/3}$	Duration	W_{Eq} (3)
	Knots	NM	ft	sec		hours	ft-lbs/ft/year
E	22 5	135	8 5	7 9	0 027	14	3600 10^8
SE	12 5	135	3 6	5 8	0 021	20	474 10^8
S	12 0	135	3.3	5 7	0 020	21	390 10^8
SW	14 5	250	5 0	7 3	0 018	30	1150 10^8
W	12 0	250	3 5	6 5	0 019	35	500 10^8

Table 2 e sin 2 α_b corresponds to Fig 12 for various steepness ratios

Fig 12		Fig 8		e sin 2 α_b = 2 cos α sin α_b	
Direction	α_o	H/L		H/L	
		0 02	0 03	0 02	0 03
S-43° E	70°	0 31	0 37	0 212	0 253
S	27°	0 19	0 23	0 321	0 41
SW	18°	0 13	0 16	0 24	0 304
W-3° S	60°	0 32	0 373	0 32	0 37

Table 3 e sin 2 α_b corresponds to Fig 13 for various steepness ratios

Fig 13		Fig 8		e sin 2 α_b = 2 cos α sin α_b	
Direction	α_b	H/L		H/L	
		0 02	0 03	0 02	0 03
S-40° E	72°	0 31	0 366	0 192	0 229
S	32°	0 215	0 262	0 365	0 434
SW	13°	0 092	0 118	0 179	0 23
W-3° S	55°	0 312	0 364	0 358	0 418

Table 4 - Littoral drift west of Dyrholaey Fig 12
(Solution of Eq (4 a) and (4 b))

Direction	α_o	Reduction of wave energy from dom direct	Q in cubic yards per year	
			H/L	
			0 02	0 03
E	~	0 5(0 4)^2	$- 110$ k 10^8	$- 110$ k 10^8
S-43^o E	70^o	2 20/ 45=0 89	$- 43$ k 10^8	$- 51$ k 10^8
S	27^o	1 0	$- 63$ k 10^8	$- 80$ k 10^8
SW	18^o	1 0	$+ 142$ k 10^8	$+ 175$ k 10^8
W-3^o S	60^o	2 19 5/45=0 87	$+ 69$ k 10^8	$+ 80$ k 10^8
			$- 5$ k 10^8	$+ 14$ k 10^8
			ave Q = $+ 5$ k 10^8	

+ means eastward drift
- means westward drift

Table 5 - Littoral drift west of Dyrholaey when the shoreline is turned 5 degrees clockwise Fig 13
(Solution of Eq (4 a) and (4 b)

Direction	α_o	Reduction of wave energy from dom direct	Q in cubic yards per year	
			H/L	
			0 02	0 03
E	~	0 5(0 4)^2	$- 110$ k 10^8	$- 110$ k 10^8
S-40^o E	72^o	2 18/145=0 8	$- 36$ k 10^8	$- 43$ k 10^8
S	32^o	1 0	$- 72$ k 10^8	$- 85$ k 10^8
SW	13^o	1 0	$+ 103$ k 10^8	$+ 132$ k 10^8
W-3^o S	55^o	2 19 5/45=0 87	$+ 78$ k 10^8	$+ 91$ k 10^8
			$- 37$ k 10^8	$- 15$ k 10^8
			ave Q = $- 26$ k 10^8	

+ means eastward drift
- means westward drift

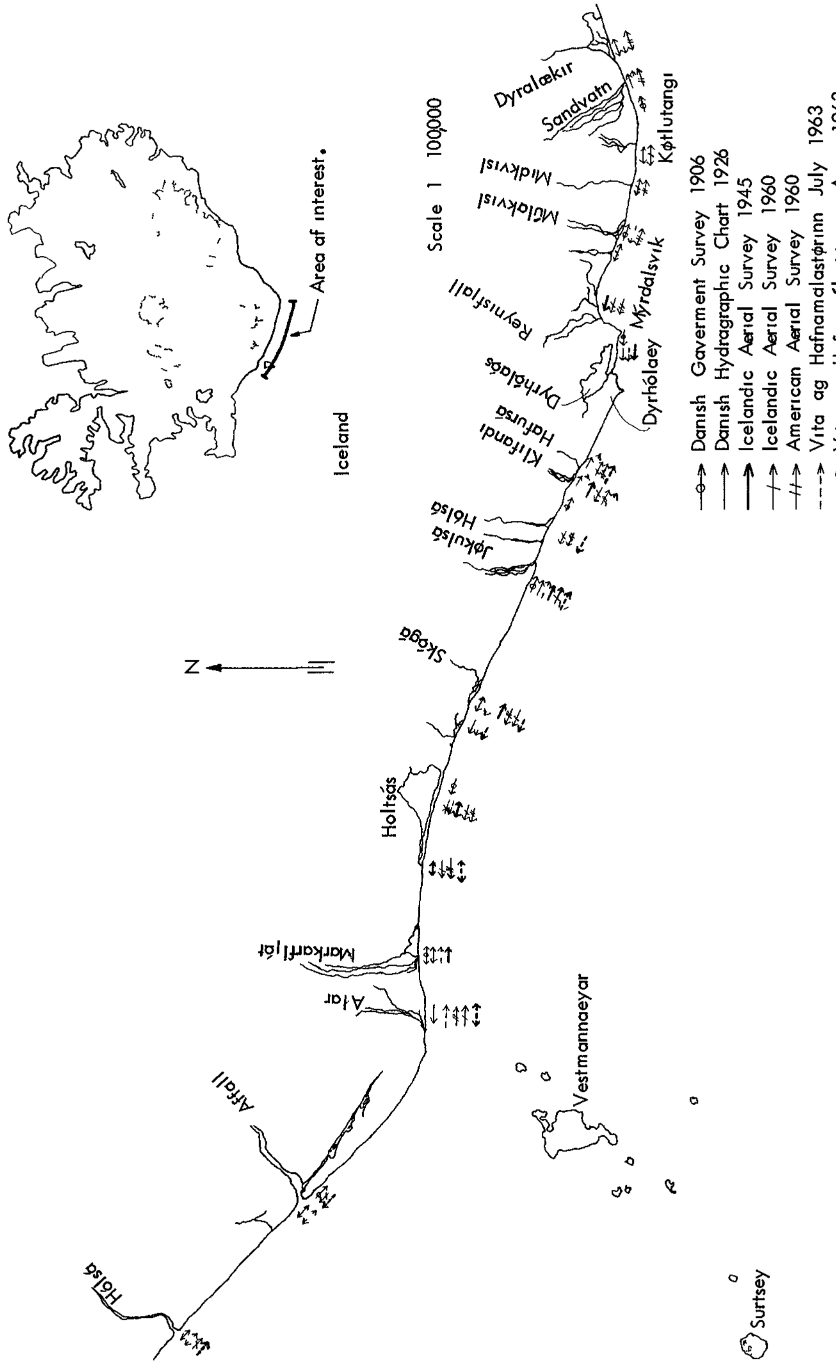

Fig. 1. Littoral drift investigatian an the Icelandic sauth coast.

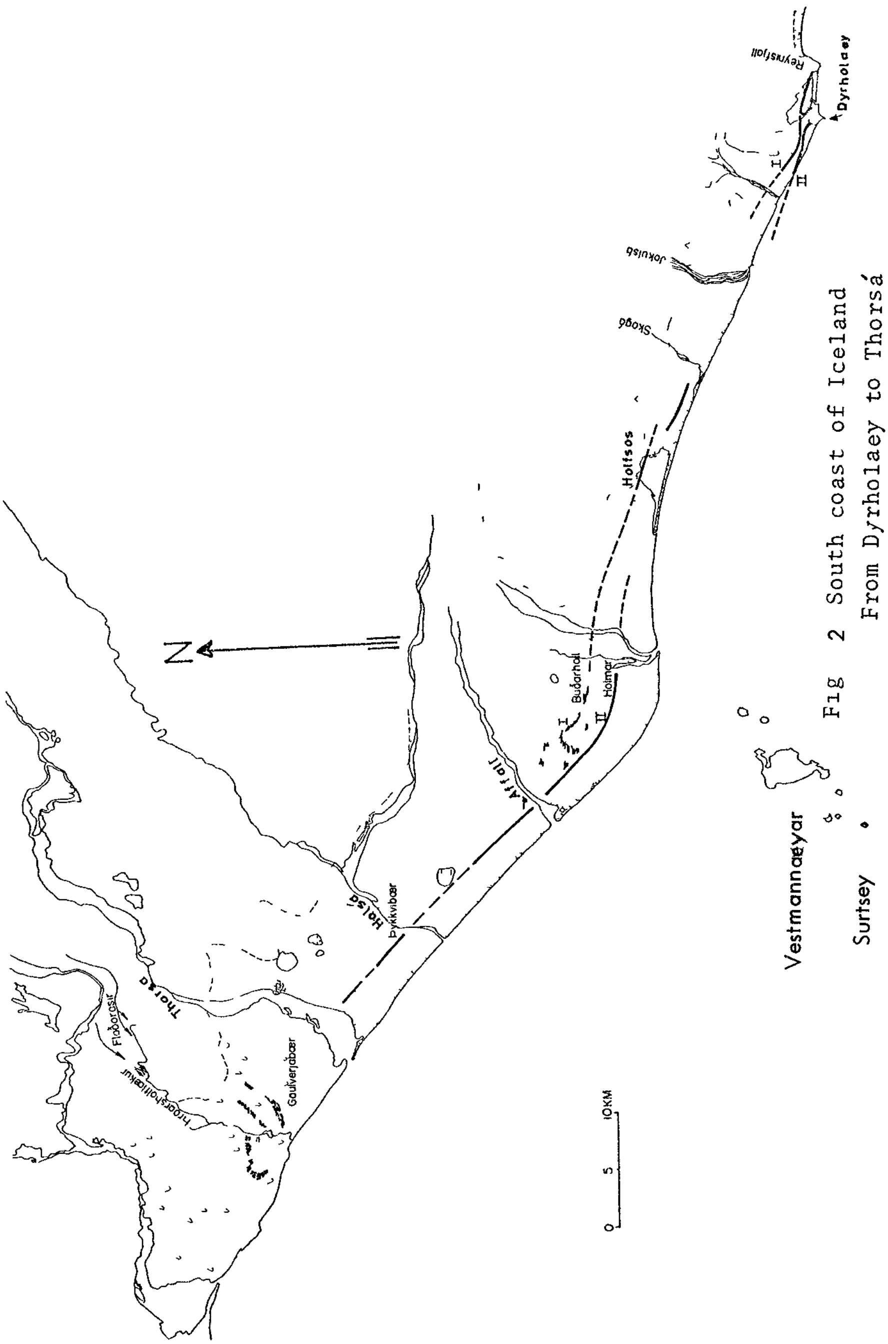

Fig 2 South coast of Iceland
From Dyrholaey to Thorsá

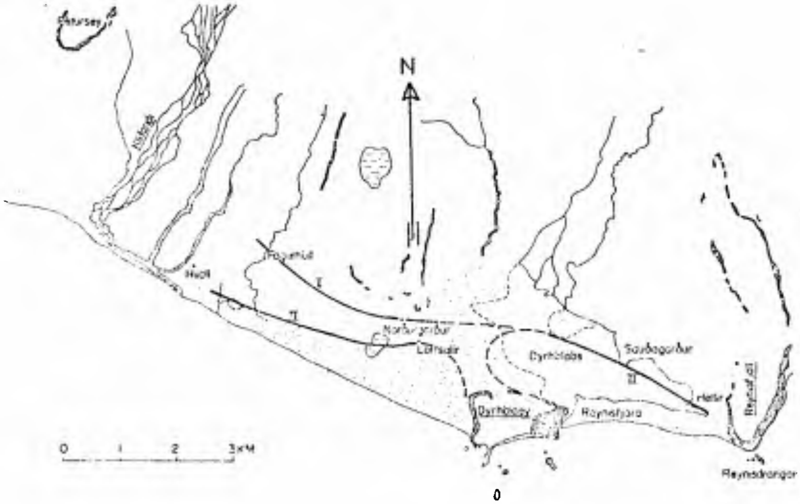

Fig. 3 South coast of Iceland
The area around Dyrholaey

Fig. 4. Surtsey two days after its eruption, Nov. 16, 1963

Fig. 5. Surtsey has emerged from the bottom of the sea on Nov. 26, 1963

Fig. 6. Surtsey, October 23, 1964

Fig. 7 Outlines of Surtsey during 1965 to 1967.

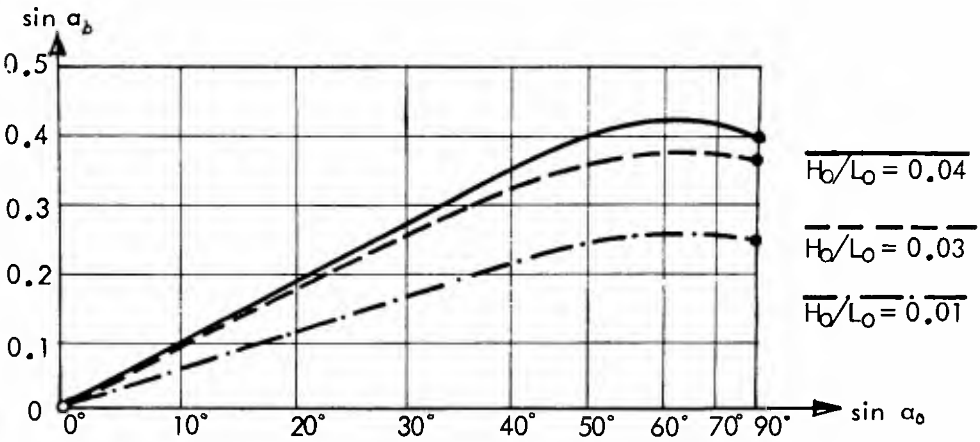

Fig. 8.

Relationships between sin a_0 and sin a_b for different steepness ratios of the waves.

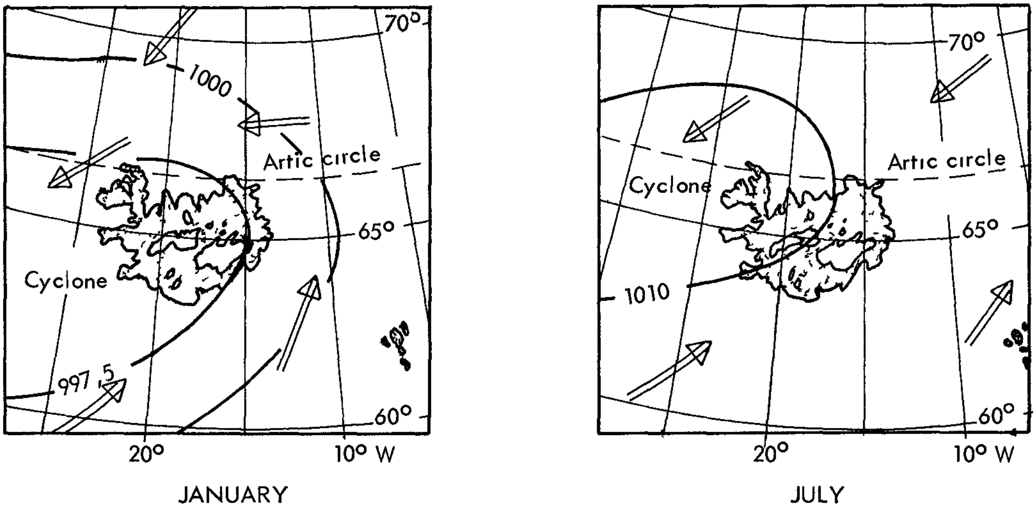

FIG 9 Characteristic cyclones and dominant wind directions

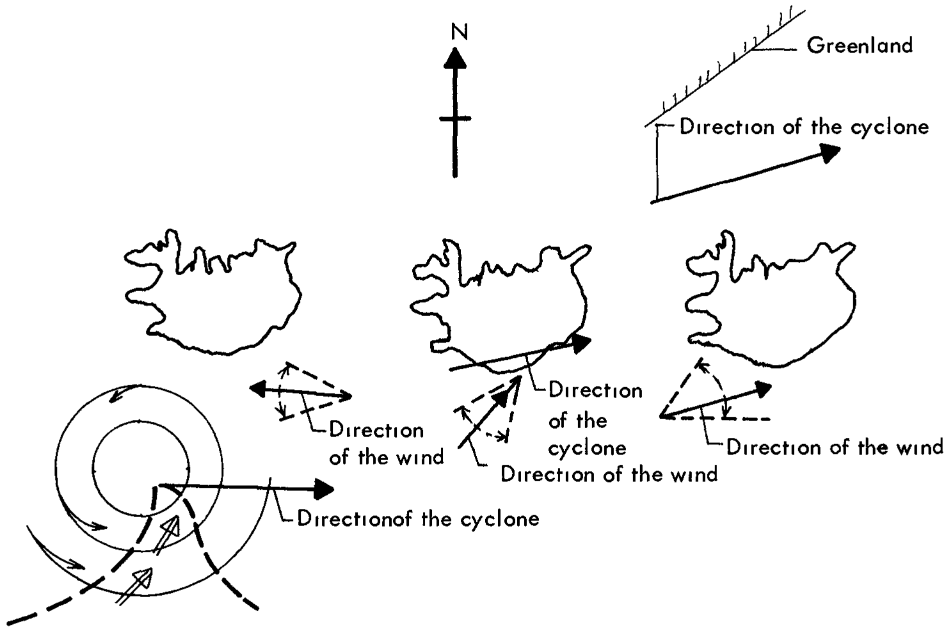

FIG 10 Characteristic wind direction for the tree paths of the cyclones

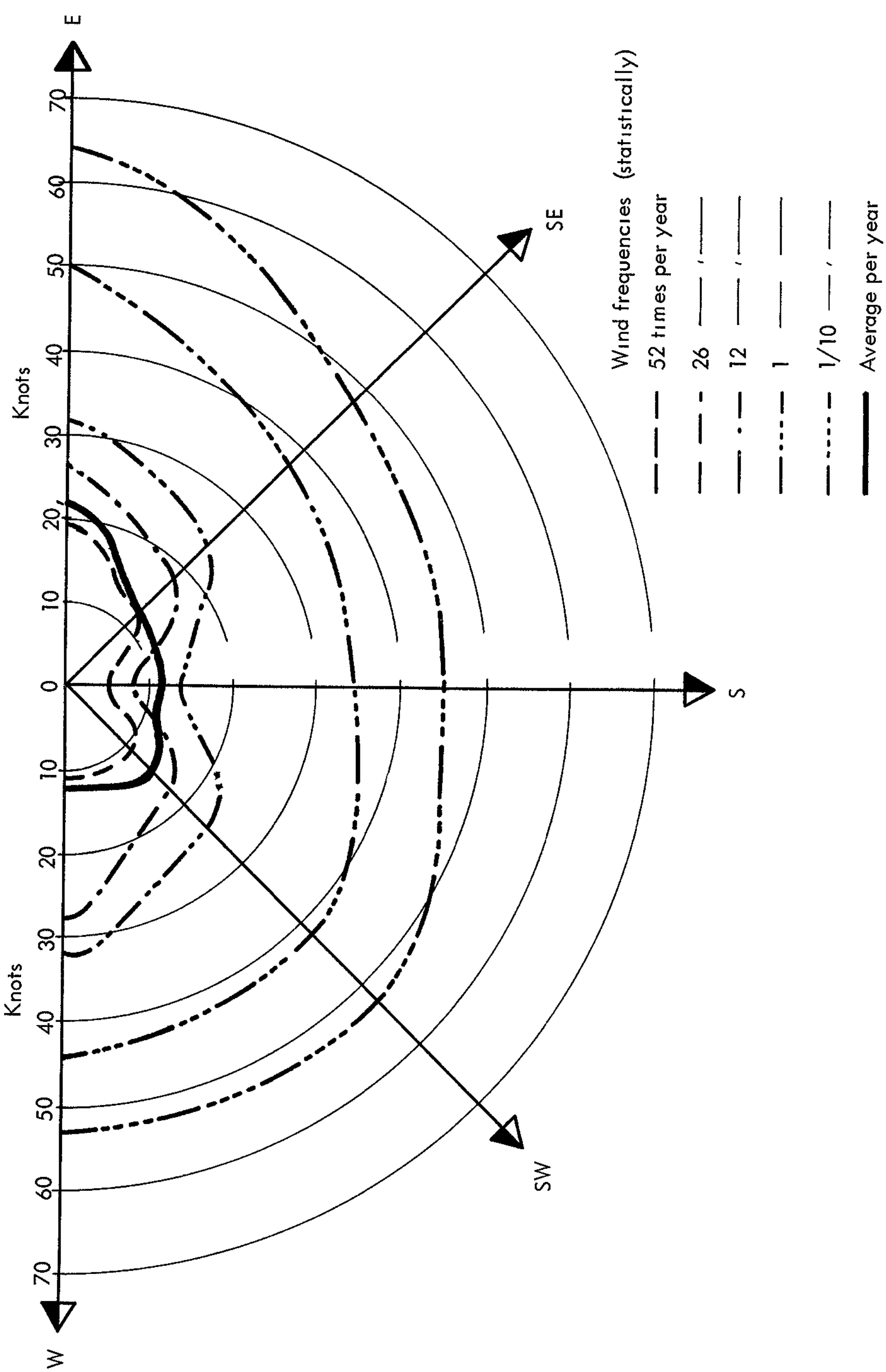

FIG 11 Wind freqency diagram, the South coast of Iceland

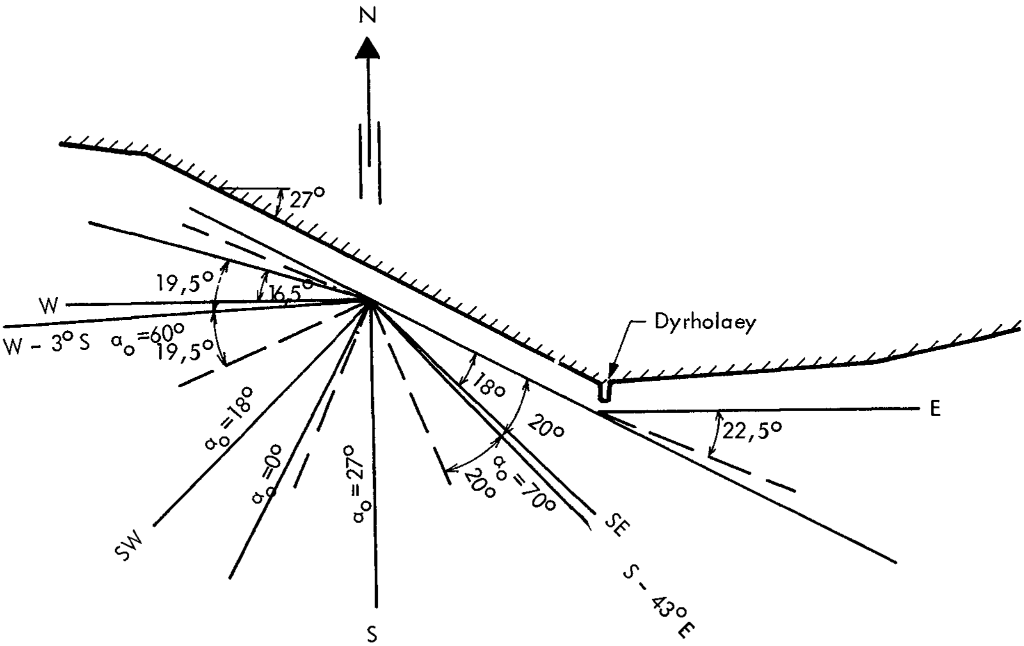

FIG 12 The boundary conditions west of DYRHOLAEY

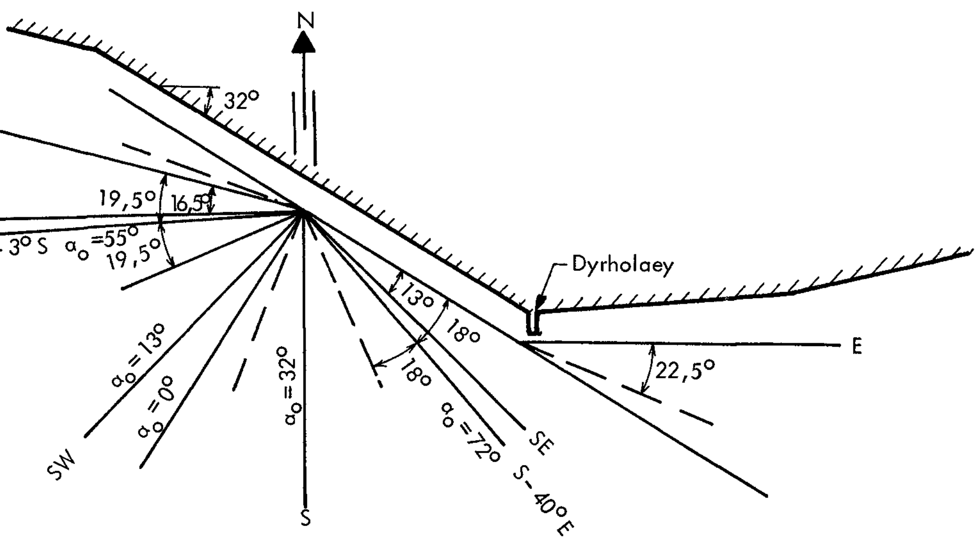

FIG 13 The boundary conditions west of DYRHOLAEY when the shoreline is turned 5 degrees clockwise